Aerobraking of High-Speed Ground Transportation Vehicles

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A JPL-sponsored aerodynamic testing program has been initiated to perform initial investigations on the effectiveness of a series of aerodynamic brakes on a long cylindrical body. The development of the experimental program is presented in this article and a description of the model and test configuration is given. Preliminary results from a low subsonic wind tunnel test using three standard test techniques are also discussed. A moving-model drop-wire facility has been constructed and initial testing is currently underway. This data, which more correctly simulates the viscous interactions of the model with the ground plane, will be compared with the wind tunnel data and used to develop analytical prediction methods.

Introduction

The significant amounts of kinetic energy present in high-speed ground transportation vehicles present serious problems during both normal and emergency operation. Friction braking systems adequate for trains operating at normal speeds, as well as some proposed nonfriction systems, are complicated by heat dissipation systems that become even larger as speeds increase. However, additional braking can be obtained by aerodynamic brakes, or panels, which can be attached to the train and extended when necessary. All energy is dissipated directly to the air and complicated coolers are not required. In addition, since aerodynamic forces are proportional to the square of velocity, this type of braking rapidly increases in effectiveness as speed increases. While the effect of a single brake located near the front of a vehicle can be estimated with confidence, little is known of the effects of a cascade of such brakes spaced along the entire length of a long vehicle.

The flow disturbances created by a brake are expected to decrease the effectiveness of any succeeding brakes. Recommendations have been made in References 1 and 2 that an aerodynamic testing program be

undertaken in this area. Because such a small amount of reliable information is available, a very simple experiment was developed utilizing idealized models to yield useful preliminary results that can be applied to evaluation of the potential of aerodynamic braking as well as to indicate specific configurations of most promise for further investigation.

Approach

Scale model aerodynamic tests are usually performed in wind tunnels. In such cases where the vehicle in its normal operation travels near the ground, the ground boundary is simulated by the insertion of a ground board in the wind tunnel, thereby minimizing the influence of slow-speed flow near the tunnel wall (boundary layer). Another wind tunnel technique is to mount two identical models in the unobstructed test area, one as the mirror image of the other. Both techniques provide only an imperfect simulation of the ground interaction effects and attempts have been made with varying success to improve the ground board technique by removing the boundary layer or providing a moving ground belt.

In the main efforts of this program, a direct approach to the interaction problem has been undertaken because the turbulence induced by the extended brakes complicates the problem and makes the need for a more accurate simulation more important. This is achieved by using a moving model while the ground plane is stationary. This first generation experimental program uses a 15.24-m (50-ft)[1] vertical guide wire in close proximity to a ground plane and on which simple models of train-like vehicles (long, circular cylinders) with arrays of extended brakes slide by means of bearings on the model axis of symmetry. Braking effectiveness of the arrays will be determined by model velocity measurements under near-equilibrium conditions; high-speed photography will be used to investigate local flow conditions on the model. A range of Reynolds numbers will be obtained by varying the model velocity and the model diameter. These tests are to be augmented by small-scale wind tunnel tests.

Wind Tunnel Test Configuration

To minimize the length of the entire program, work was begun on the small-scale wind tunnel tests while construction of the drop-wire apparatus was under way. These wind tunnel tests and the drop-wire apparatus are now complete. The wind tunnel model is shown in Figures 1 and 2. It is a basic cylindrical model which simulates a train consisting of four 25.908-m (85-ft) cars at a scale of 0.00854. The model length and diameter

[1] Values in customary units are included in parentheses after values in SI (International System) units if the customary units were used in the measurements or calculations.

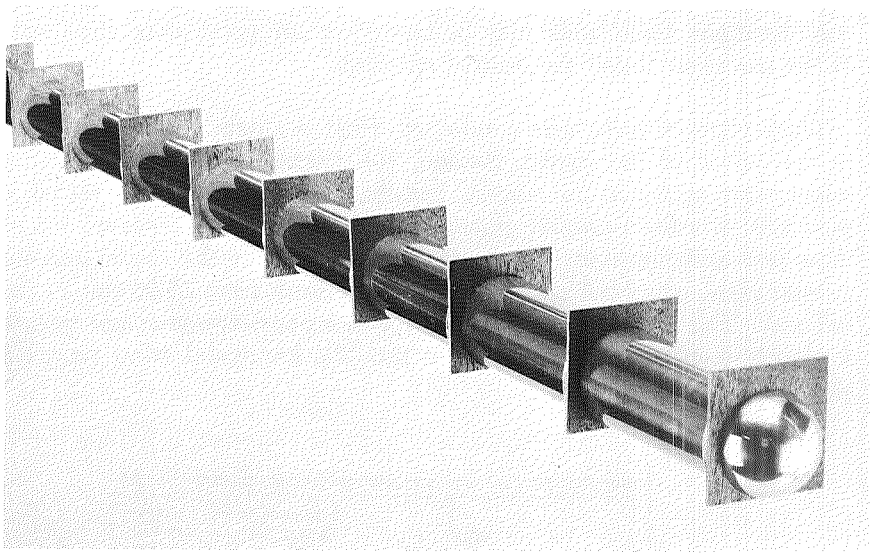

Figure 1. Wind tunnel model with brakes

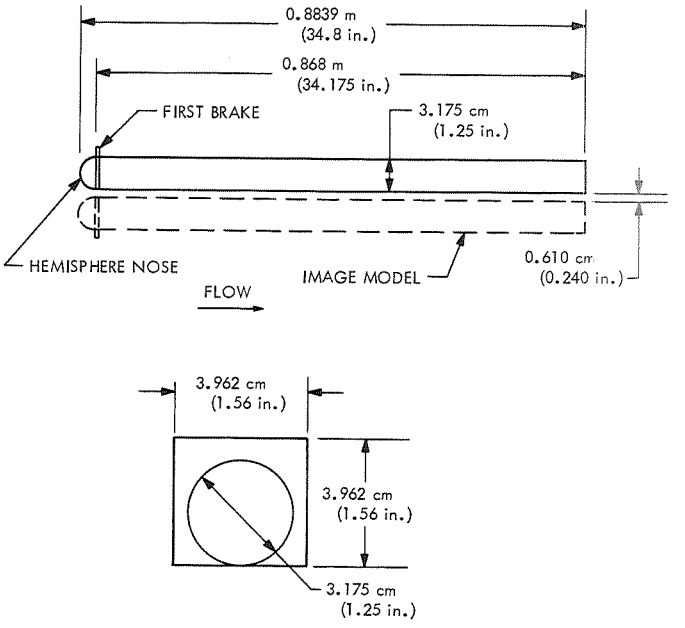

Figure 2. Schematic of wind tunnel model

are 0.8839 m (34.8 in.) and 3.175 cm (1.25 in.), respectively. The rectangular aerodynamic brakes were designed to approximate realistic full-scale brakes and were also satisfactory from wind tunnel blockage considerations. Each brake may be located at any point along the length of the model to obtain the desired spacings.

Three types of tests were conducted. First, a single model was tested in the center of the tunnel. Second, the original model and a mirror image were tested in the tunnel. Finally, a single model was tested in proximity to a fixed ground plane. Brake spacings were repeated for all three test configurations. The basic distance between the model and the ground plane was 0.305 cm (0.12 in.) scaled down from 35.56 cm (14 in.) full scale. This figure was doubled for the distance between image models. A sketch of a typical installation in the JPL low-speed wind tunnel is shown in Figure 3.

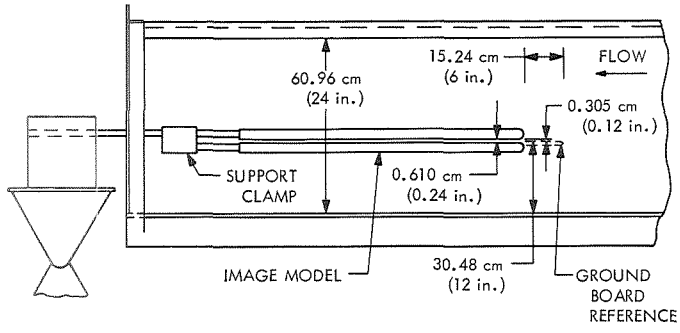

Figure 3. Wind tunnel model installation

Preliminary Results and Discussion

The primary wind tunnel measurement, axial force, was made with an internal three-component strain gage balance. Normal force and pitching moment were also recorded. Data have been reduced to a drag coefficient based on the model cylindrical cross-sectional area of 7.917 cm^2 (1.23 $in.^2$), which is approximately the same as that for one brake.

Figure 4 shows a typical data plot of the drag coefficient C_D as a function of the number of brakes installed on the model at a spacing of 12.7 cm (5 in.). All data with the exception of the first brake point may be faired smoothly. Differences between the image and ground plane models clearly illustrates the problem of selecting the proper method of testing, in a wind tunnel, a vehicle moving over a fixed surface. All of the results of the wind tunnel test will not be discussed here. However, some effects are noteworthy. Three complete sets of brake spacings were tested: 7.62, 12.70, 15.24 cm (3, 5, and 6 in.). The total drag on the four-car train model was highest for the 7.62-cm (3-in.) brake spacing because

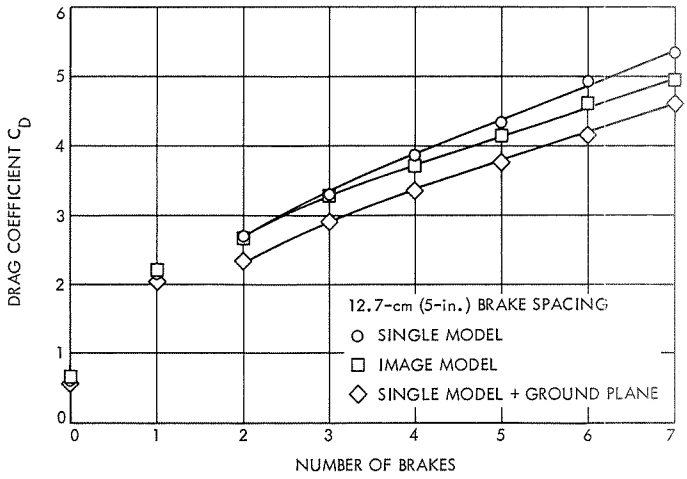

Figure 4. Effect of brake additions

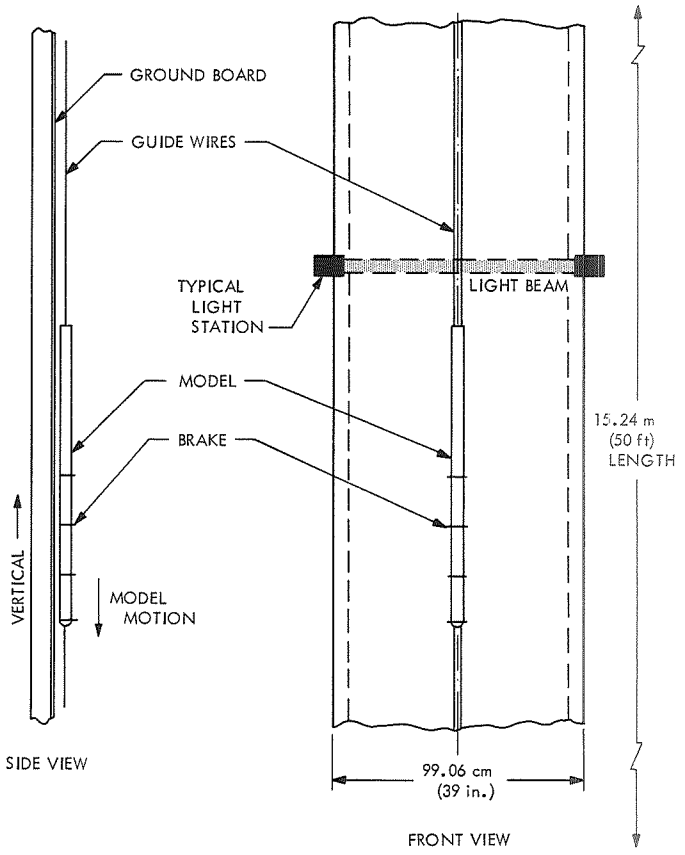

Figure 5. Drop-wire installation

of the greater total number of brakes, twelve as compared to seven for the 12.7-cm (5-in.) spacing. However, the drag increment per brake is actually less for a 7.62-cm (3-in.) spacing. Other tests concerned the effect of brake venting in an attempt to add high-energy air to each succeeding brake in the cascade. The result was a decrease in drag when 10 and 15% of the surface area of each brake was ventilated. Increasing the clearance between the model and the ground plane resulted in drag increases which approach the data obtained for the single model in free air.

The wind tunnel test completes the supporting information necessary for evaluating the drop-wire program. The primary data, with the moving model, is now being obtained on the drop-wire system shown in schematic form in Figure 5. To operate, the model is raised to the top of the wire guides and released. During the fall, the model interrupts the light beams, and sensors register the time and distance for the model's passage. Velocity and corresponding drag coefficient may be calculated from these data. Model drops will be made with and without a ground plane for varying brake spacings. A range of Reynolds numbers will be obtained by varying model terminal velocity and model diameter. Comparison of these data with those of the wind tunnel experiment is expected to give significant insight into the problem of brake effectiveness beyond that of the first brake with a minimum of ground plane viscous interactions.

References

1. *Development of Nonfriction Braking Systems for High Speed Trains,* No. YM-2811-K-3. Cornell Aeronautical Laboratory, Inc., Vehicle Research Department, Buffalo, N.Y., Apr. 1970.
2. *High Speed Rail Systems Study by TRW Systems.* TRW Inc., Redondo Beach, Calif., 1969.